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D28: A DSS to assist in operational control of plant for optimisation of biogas production and methane content

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Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission	
RE	Restricted to a group specified by the consortium (including the	
CO	Confidential, only for members of the consortium (including the Commission Services)	

D28: A DSS to assist in operational control of plant for optimisation of biogas production and methane content

Objectives

Objective of this Deliverable was the development of a decision support system (DSS) based on fuzzy logic to optimise the conversion process of biomass into gaseous fuels. "*DSS are computer-based systems used to assist and aid decision makers in their decision making processes*" (Bogardi 2004) Normally such a system consists of several dimensions, where the actual decision-making is important, but nevertheless only a part of the whole DSS (Bogardi 2004). This DSS is then thought to identify process control strategies to yield a high methane content final product.

1. Requirement Analysis

The requirement analysis consists of an analysis of the required tasks, a description of the users and organisations where the DSS should be implemented.

1.1. Task Profile

The amount of biogas production and the methane content are depending on a lot of different parameter; for instance the used substrates, the operation mode (batch, quasi-continuous or continuous), the used temperature range (mesophilic (35°C) or thermophilic (60°C)), the type of reactor, and so forth.

This DSS should show:

- ♦ which of the available crops and in what mixture and what amount, would be the best to achieve the highest possible biogas production and methane content,
- ♦ by avoiding a process overload at the same time.

1.2. User Profile

This DSS should be at first for plant operators of biogas plants. These people are normally moderately educated, therefore they are characterised as naive user. Thus the DSS should be easy to use and should have a good tutorial and training possibility. Mostly they are passive users and are not experienced with computers. They generally do not have high expectations in this kind of technique, so they have to be persuaded that this will lead to higher efficiency of their plants, and thus a higher income. So also a kind of support system or certification from the government or the European Union for plant operators, who use such a system, would be an advantage. For these users, the parameters that must be provided should be minimised.
On the other hand, DSS can also be used by scientists, who work on anaerobic digestion, to support their work. These users have good cognitive skills and typically are advanced computer users.

1.3. Organisation

For plant operators such a DSS means additional work and expenses, thus it will take a lot of persuading that they see the advantages of this DSS and use the system. It should be possible to simply integrate the DSS in daily work routine.

For a university it means some investment costs, but no additional work on the contrary, this DSS could be a base for their work.
The result of the requirement analysis are summarised in the Three-Dimension-Requirement-Matrix (Figure 1.3.1).

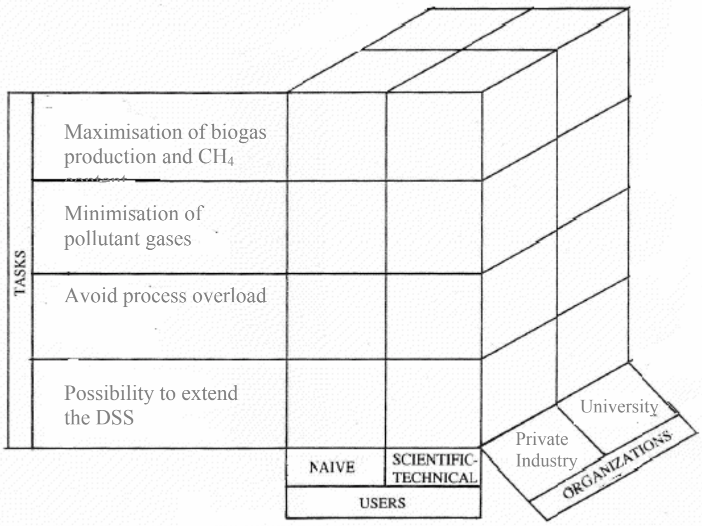

Figure 1.3.1: Three Dimension Requirement Matrix adapted from Bogardi (Bogardi 2004)

2. <u>Method selection</u>

Different models can be used to characterise the here described problem, such as mathematical (mechanistic) models, for example "Anaerobic Digestion Model No.1" (ADM1) (Batstone *et al.,* 2002) or artificial neural networks and also fuzzy logic based control systems.

Artificial neural networks (ANN) are empirical models, especially suitable for non-linear systems. An ANN consists of simple processing elements (neurones), which are linked in a network by a set of weights. The network itself is determined by its architecture, the dimension of the weights and the mode of operation of the processing elements (Strik 2004). The ANNs can also be combined with a fuzzy optimisation algorithm.
Advantage of this model is that, it has a self-learning algorithm and easy to use, even from naive users. Drawbacks are that for artificial neural networks, a bulky amount of data is necessary and that it is not possible "to look into the system". The performance of neuronal network depends mostly on the available data for training the network (Steyer et al., 2005), but it has been already shown that this is functional control method (see for example (Holubar *et al.,* 2000)).

Mechanistic models, describe the physical, chemical and biochemical processes of the anaerobic digestion process mathematically. The calibration of this kind of model can be very time-consuming and complex, but can be reduced to a limited amount of sensitive parameters (Holvoet et al., 2004). A lot of different anaerobic digestion models were developed in the last 40 years, such as the Hydrolysis controlled anaerobic digestion from Jain (Jain et al., 1991). Angelidaki and co-workers (Angelidaki et al., 1993) developed a Mathematical Model Focusing on Ammonia inhibition and further developments (Angelidaki et al., 1998). The simulation model <Methane> should be universal model, capable to describe all important factors of the process (Vavilin et al., 1993; Vavilin et al., 2000). And naturally the already above metntioned ADM1 (Batstone *et al.,* 2002). Advantage of this method is that the model is "transparent" and the results are comprehensible. Disadvantage of the ADM1 is that it has to be a bit adapted for the use of energy crops in anaerobic digestion. Moreover, there is only a limited amount of biochemical parameters available, especially for the thermophilic temperature range (Batstone *et al.,* 2002). Thus most parameters have to be determined experimental.

That means that fuzzy numbers are uncertain numbers, where some values can be defined as more possible then others (Bogardi 2004). This technique is based on control rules, mostly in form of descriptive terms. Normally, a FL based control consists of the fuzzyfication of an input, the application of the interference rules and the subsequent defuzzyfication of the output. As an expert system (≠ a model!), this control tool needs process specific experience. Compared to the model based control tools, however, a reduced amount of measured data, only a short observation (2-3 month) is necessary. Moreover is it possible to minimise the necessary parameters and no substrate information is necessary.

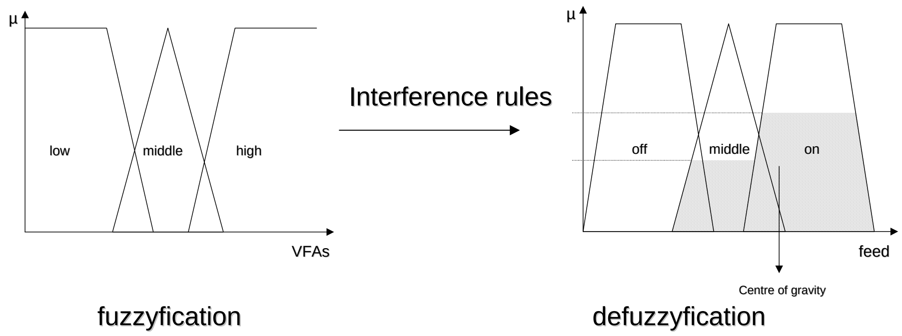

Figure 1.3.1: Action chain in Fuzzy based control tool

In this case ANN would be a possibility alternative to use, but as a lot of data is needed there; it was decided to reject this method. To use the ADM1 or another mathematical model would be an interesting method, as less overall data would be necessary, but the original ADM1 has to be simplified to be used in a control tool and furthermore a database on kinetic and biochemical parameters will be necessary, as a lot of input parameter are asked, which are impossible to measure in a technical plant. Therefore and also according to the above motioned advantages it was decided to build a fuzzy logic based DSS.

3. Fuzzy Logic based Decision Support System

3.1. Fuzzy Logic Based Decision Support System

Different FL based control tools were developed, mostly based on a FL Tool designed during the AMONCO project, which was now enhanced to improve the control performance.
The different Control Tools were then tested with the ADM1 (Batstone *et al.,* 2002) and compared with a composite programming based ranking method, to find the best structure, but also the ideal membership functions.
Composite Programming is an extension of Compromise Programming, which is itself one approach of multiple criterion decision making (Bogardi 2004). The principle of multiple decisions making is to maximise the satisfaction of the different conflicting objectives in order to find the best option (Bogardi 2004). Compromise Programming is

measuring the distance between the actual solution and the ideal solution and then selects the minimum distance. Composite Programming is working with a hierarchical and normalised distance type. Here, the process is broken down in its elementary compounds, and then grouped in broader and higher levelled indicators (Bogardi 2004).
As appraisal factors the gas production (gp), the methane content (mc), the concentration of the acetic acid (acetate), the concentration of the propionic acid (prop), the total concentration of volatile fatty acids (vfa), the COD reduction (%abbau) and the pH were chosen (data not shown).
Hereby 47 different scenarios were tested, changing either one or more "Fuzzy Blocks" (either changing only the input membership functions of the block or also changing the output membership functions, with 60 different values for each membership function (also varying between trapezoid and triangle form).

3.2. Structure of the Fuzzy Logic based DSS

The finally chosen Fuzzy Tool has the following structure (Figure 3.2.1): Input of this Tool was the concentration of the propionic acid of the current day and the day before, the pH of the current day and the day before and also the gas production of the current day and the methane content of the current day. The output is the organic loading rate of the next day respectively the feed volume.
The used fuzzy methodology was the fuzzy interference method by Mamdani (for all used Fuzzy Tools) (Mamdani and Assilian 1975).

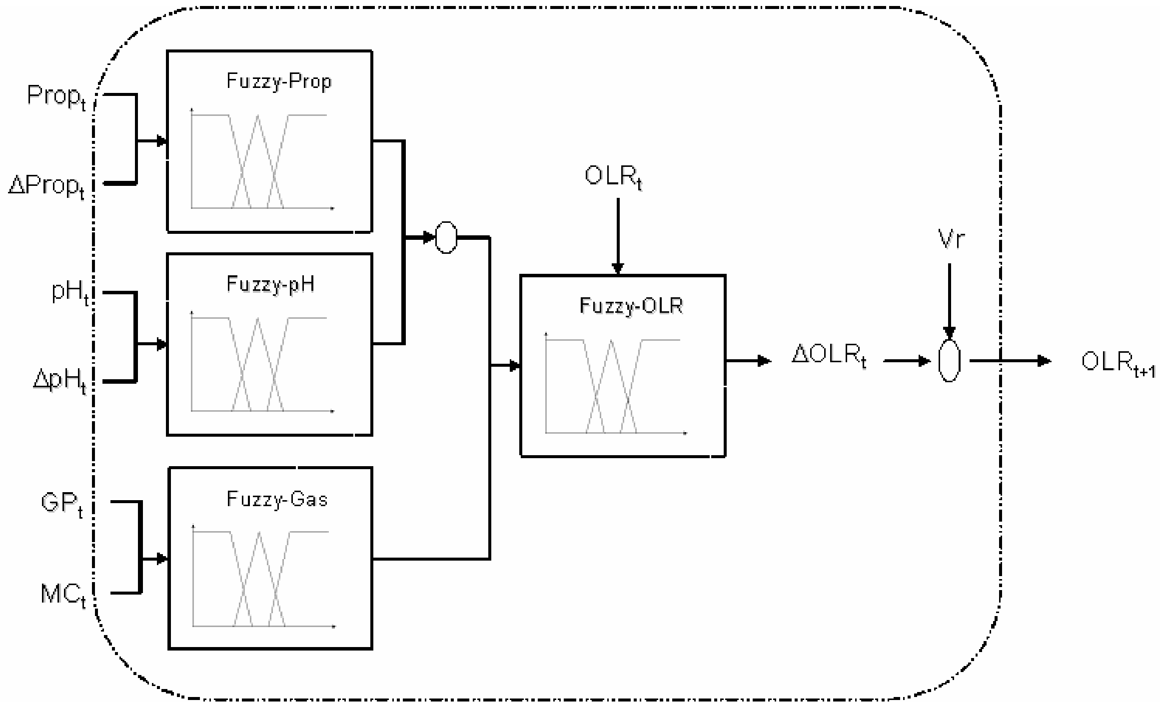

Figure 3.2.1: Structure of the chosen Fuzzy Tool

Figure 3.2.2 shows the membership functions for the used Fuzzy Tool.

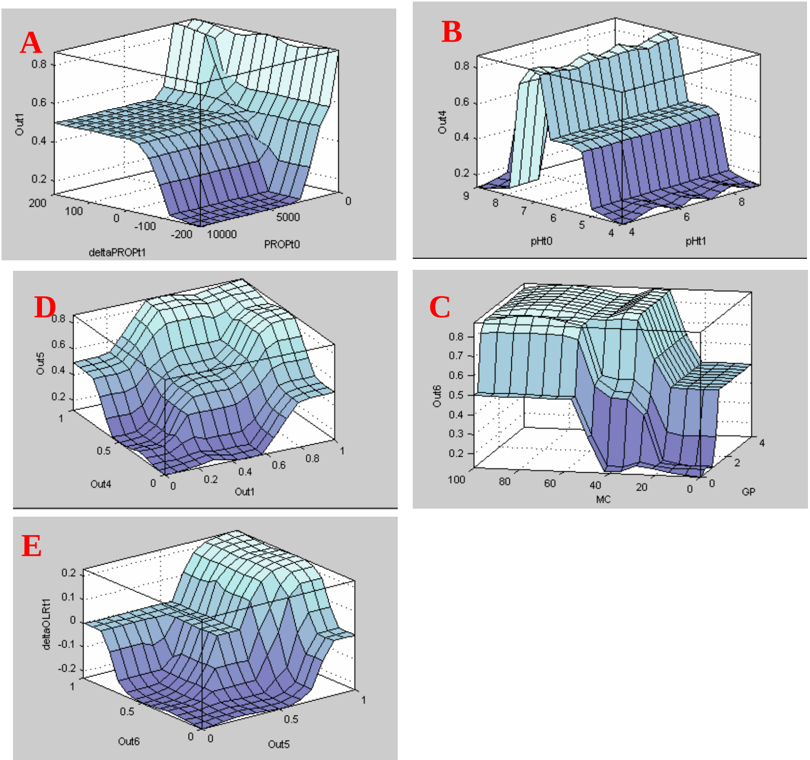

Figure 3.2.2: Membership functions of the Fuzzy Logic based Decision Support System: Membership function of A) propionic acid, B) pH and C) Methane content and gas production

The Fuzzy based DSS now is written in the graphical programming system LABVIEW®, with an implementation of the Fuzzy algorithm as MATLAB® script and the Fuzzy Logic Toolbox, compiled in MATLAB® executable (Figure 3.2.3).

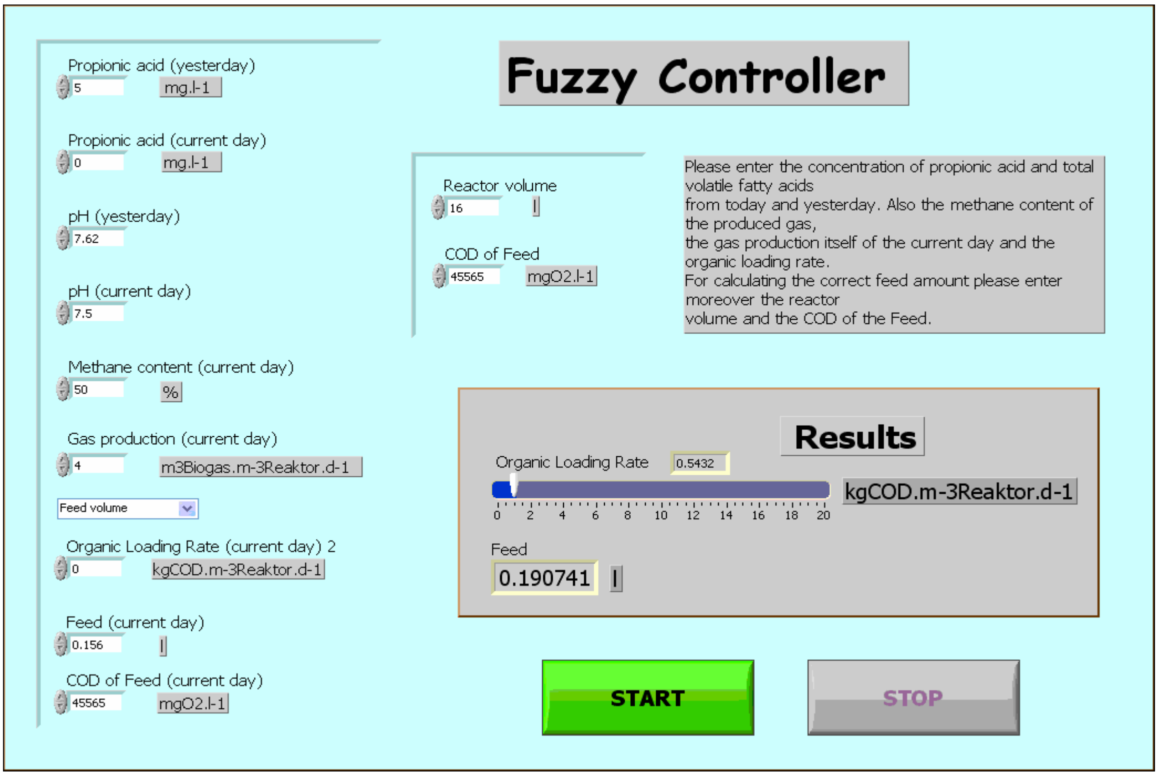

Figure 3.2.3: Screenshot of the Fuzzy Logic based Decision Support System

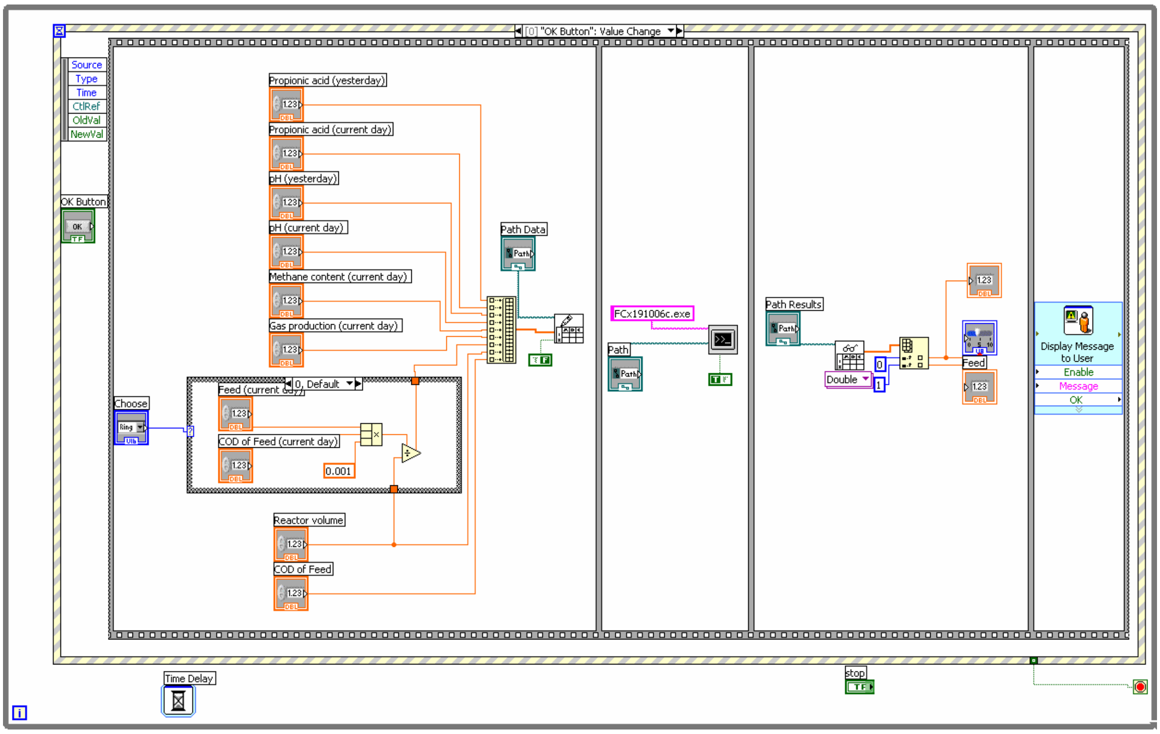

Figure 3.2.4: Labview Structure of the Fuzzy Logic based Decision Support System

3.3. Laboratory Experiments

Two Fuzzy tools were tested in the Laboratory Reactors. These experiments are performed in two 20 l (18 l working volume) lab-scale anaerobic completely stirred tank reactors (CSTR). The operation temperature for the reactors is set at 35 °C (mesophilic) and 60°C (thermophilic), respectively. The used reactor set-up (Figure 3.3.1) was, with slight differences, the same as described by Holubar et al.(2003) (Holubar et al., 2003).
Biogas production, temperature and methane content are measured online via Fieldpoint modules (National Instruments, Austria). The pH, COD, volatile suspended solids (VSS) and the volatile fatty acids (VFA) are determined offline.
The COD is measured with the LCK 114 test kit (HACH LANGE, Germany) and sulphate concentration with the LCK 153 test kit (HACH LANGE, Germany). The VSS, ammonium and the alkalinity are determined according to standard methods.
The acetate and propionate concentration as well as the total VFA concentration is analyzed using FTIR spectroscopy (Spectrum One, PERKIN ELMER, USA). The total organic carbon content (TOC) is determined with the Total organic carbon analyzer TOC-500 (Shimadzu, Japan). Total protein concentration is determined by Bradford method (Lowry et al., 1951), total carbohydrate concentration by the anthrone method (Dreywood 1946) and amino acid concentration with the ninhydrin method (Moore and Stein 1948).

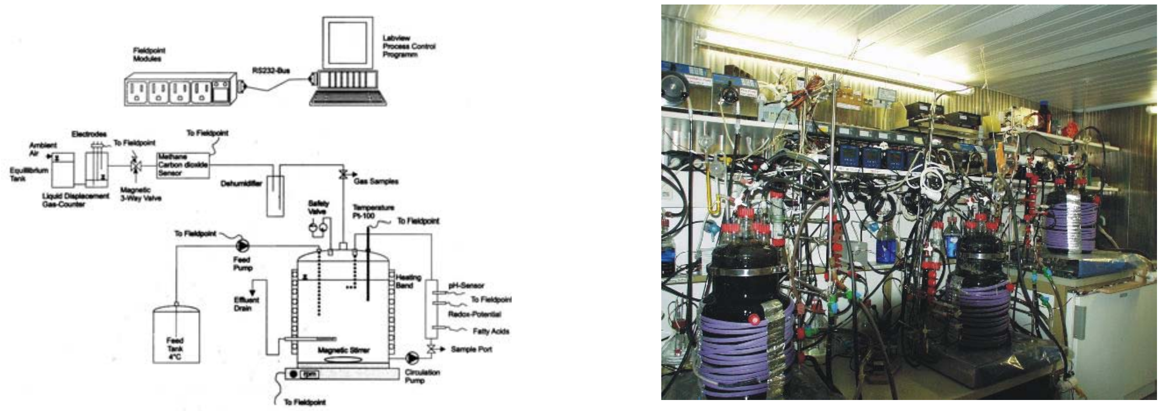

Figure 3.3.1: Reactor set-up

The first tested fuzzy tool was only partly successful (data not shown). The second fuzzy tool – and finally chosen tool - (described above) was tested in the second reactor system (Figure 3.3.2). It can be seen that by that the methane content is lightly decreased (but stabilises around 50 % Methane) during the test period, but the methane production rate is increased in the same period and the volatile fatty acid concentration remained relatively stable.

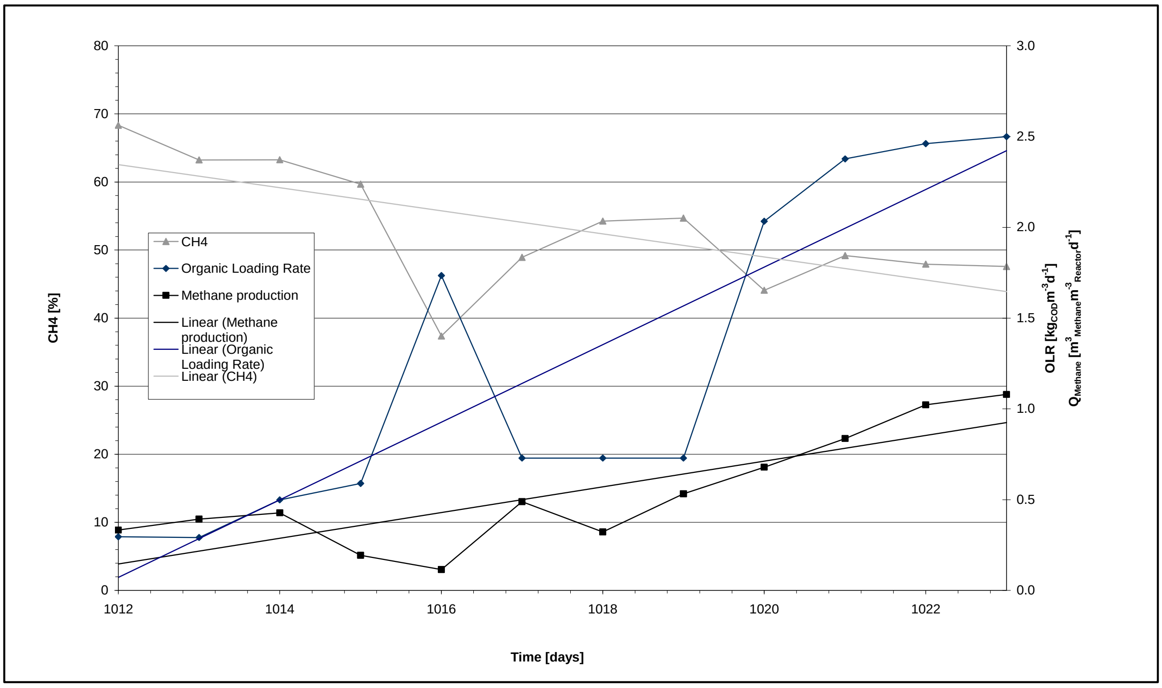

Figure 3.3.2: Test of the Fuzzy control tool in the thermophilic reactor system FM2

4. Evaluation

Finally the DSS is, to secure the functionality and usefulness, was evaluated. An evaluation for this kind of DSS is difficult, due to the fact that it depends on a lot of criteria and parameters. The evaluation here is done by:

- Showing the functionality and efficiency in laboratory reactors (see section 3.3)

Further evaluation (which is not possible in the frame of the CROPGEN project) should include:

- Testing of the tool in a technical scale reactor.
- Apart from that, it has to be evaluated, if it is easy to use for naive users, if the tutorials and training units are adequate, also if the users like the appearance of the DSS.
- Is the outcome of the DSS understandable and can it be directly implemented in the plant. This should be evaluated in form of a questionnaire.
- It has also to be evaluated if the DSS influences the structure of the organisation, the people´s positions, or the information flow. Also, how heavy side effects are, as cost factors and training.

5. Summary and Conclusion

A Fuzzy Logic based Decision Support System (DSS) was development to optimise the methane production and secure stable process performance. Therefore first a requirement and method selection was done. Followed by testing different Fuzzy structures with a composite programming based ranking method and the ADM1 (Batstone *et al.,* 2002). Moreover the DSS was tested in laboratory reactors. Here an increase of the methane production rate could be observed. Finally different suggestions for a further evaluation of the tool were made.
Generally it can be said that: It will be for sure difficult to implement such a system in technical plants, mostly to the scepticism of the plant operators, which is understandable due to a certain risk. But nevertheless this DSS is absolutely useful, and would enhance the efficiency of the plant, and therefore lead to cost optimisation.

To arrive at a broad acceptance of the DSS, it should not be too expensive, - therefore the chosen software technique (using a LabView® Runtime and a Matlab® Component Runtime – as they are free of charge) would be ideal - thus it is available also for small biogas plants, for that reason an access via internet to the DSS would be a possibility.
Also a support system or certifications would increase the willingness of the plant operators to use such a system.
The DSS should also be easy to use, which means that the user interface should be clearly arranged and self-explanatory. It should also appeal the users. The tutorial should be considerable and provided with a lot of examples.
Even though the methodology of the DSS itself is complicated, the possibility to extend the DSS should be explained in detail and easy to perform.
An implementation of such a control tool will be very complicated for existing biogas plants; therefore a possible implementation and the type of control tool should already be in mind during the planning phase of any biogas plant. Therefore improved measurement equipment and the feasibility for sampling are necessary.
Due to a certain risk in financial terms, for smaller plants a central server control tool would be optimal. This would also lead to a larger pool of operation experiences

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